

Tropical Cyclogenesis Initiated by Lee Vortices and Mesoscale Convective Complexes in East Africa

Yuh-Lang Lin
Department of Marine, Earth, and Atmospheric Sciences
North Carolina State University
Raleigh, NC 27695-8208
Phone: (919) 515-1438; fax: (919) 515-1683; email: yl_lin@ncsu.edu

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<http://rossby.meas.ncsu.edu>

LONG-TERM GOALS

To understand the generation of precursors of tropical cyclones, which form over the eastern Atlantic Ocean, the formation of a vortex and MCC to the lee of the Ethiopian Highlands, the propagation of the vortex and MCC across the African continent, and the initiation of tropical cyclones over the eastern Atlantic Ocean.

OBJECTIVES

The scientific objectives of this effort are to answer the following fundamental questions:

- (1) What are the environments and mechanisms responsible for the formation of a lee vortex associated with the pre-Alberto disturbance?
- (2) What are the environments and mechanisms responsible for the development of the associated MCC?
- (3) With a weakened easterly wave disturbance associated with the pre-Alberto vortex and MCC, is it possible to initiate the tropical cyclone over the eastern Atlantic Ocean?

APPROACH

Numerical Modeling: In order to answer the above questions, we propose to perform a series of numerical experiments and idealized simulations by using a state-of-the-art non-hydrostatic model. The simulations will be performed using three nested domains with grid resolutions of 45, 15, and 5 km. All domains will be used to answer the first and second questions for 60 hours starting at 0000 UTC 28 July 2000, while only the outer domain will be used to answer the third question for approximately 186 hours starting at 0000 UTC 28 July 2000. Individual contributing factors will be isolated by either deactivating the corresponding physical processes in the model or by performing appropriate idealized simulations.

Observational Data Analysis: The simulation results will be verified with available reanalysis data, such as NOGAPS and ECMWF reanalysis data, and be used to investigate the formation and maintenance mechanisms of the precursors and the initiation of Hurricane Alberto.

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WORK COMPLETED

- (1) Presented some preliminary results, entitled "Initiation of mesoscale convective complexes in Eastern Africa: A precursor to tropical cyclogenesis", at the 25th Conference on Hurricanes and Tropical Meteorology in San Diego, CA, during 29 April - 3 May 2002. Christopher M. Hill is a graduate student supported as a research assistant under the project.
- (2) Submitted a paper, entitled "Control parameters for track continuity and deflection associated with tropical cyclones over a mesoscale mountain", to J. Atmos. Sci. for publication. This work is related to the current project, which will help understand orographic effects on the MCC propagation in Central Africa. This is also co-sponsored by a UCAR cooperative agreement.
- (3) In addition to the control numerical experiment of the initiation of mesoscale convective complexes over the Ethiopian Highlands performed before the submission of this grant proposal, we have performed three sensitivity experiments with: (i) no latent heating, (ii) no sensible heating, and (iii) no terrain. The model specifications used in the control run are: 45-km resolution, 42 σ -levels; 136x86 horizontal grid points; 60 s time interval; 48 hour simulation starting on 00UTC 28 July 2000; Kain-Fritsch cumulus parameterization; Blackadar PBL scheme. We are in the process in extending the conference paper, which was presented in the 25th Conf. on Hurricanes and Tropical Meteorology, to a journal paper to be submitted to the Monthly Weather Review in the beginning of October 2002.
- (4) The modeling work described in (1) will be extended to use a more sophisticated mesoscale model, the COAMPS v.3.0 model, which has the moving grid capability. Nested domain simulations will also be performed by using the COAMPS model in the near future. Mr. Christopher M. Hill has learned the old version (v.2.0.15) of the COAMPS model and has been learning the new version (v.3.0) recently by attending the training session and workshop held at NRL during September 4-6. According to staff at the NRL, the new version will be available at the end of September 2002.
- (5) We have ordered and received METEOSAT IR and VIS satellite data from EUMETSAT. Based on storm track data from the National Hurricane Center, we have identified 55 tropical depressions (TD) that formed to the east of 40°W during the period of 1985-2001. These systems are being examined using the satellite data. Based on the satellite data of Hurricanes Alberto, Isaac and Joyce (all in 2000), we have identified five stages of the vortex/MCC life cycle over the African continent. Along with precursors to Hurricane Alberto, we plan to study the precursors associated with Hurricanes Isaac and Joyce by performing numerical simulations and observational data analyses. Ms. Chenjie Huang, a graduate research assistant, and Ms. Katie Robertson, an undergraduate research assistant, are supporting these tasks.
- (6) We have also downloaded NOGAPS data, which has been used to initialize the mesoscale model for simulating the initial phase of the precursor formation and will be used for initializing COMAPS model in the near future as well as for tracing the precursors in a more quantitative way. Preliminary results of vorticity evolution for pre-Isaac system near the Ethiopian Highlands have been performed. Both Ms. Huang and Ms. Robertson are supporting this task.

RESULTS

In the course of tropical cyclone research, points of origin have been found to be important in determining the potential track and intensity of the cyclones. Among the significant regions of tropical cyclogenesis in the world is the tropical eastern Atlantic Ocean, particularly near the Cape Verde Islands. This region is known to incubate many of the disturbances that become major hurricanes in the Atlantic Ocean basin. Tropical disturbances, which are associated with African easterly waves emerging from the West African coast, are the known nuclei for these tropical cyclones. Frank (1970) briefly mentions the possibility that easterly waves may develop downstream of the Ethiopian Highlands (EH) as a result of orographic influence on the easterly flow.

During the hurricane season of 2000, several tropical cyclones began as disturbances over the African continent. A tropical cyclone, which would later become Hurricane Alberto, was traced as a MCC backward in time to the EH, where the MCC was first seen to develop late on 28 July 2000. After tracking across the entire African continent over a four-day period (Fig. 1), the disturbance emerged off the West African coast on 03 August 2000. Based on a tropical cyclone report from the National Hurricane Center, the disturbance quickly developed into a tropical storm on 04 August 2000 over the eastern Atlantic Ocean, and became a hurricane early on 06 August 2000. Hurricane Alberto would later become a long-lived hurricane with a peak intensity of category four.

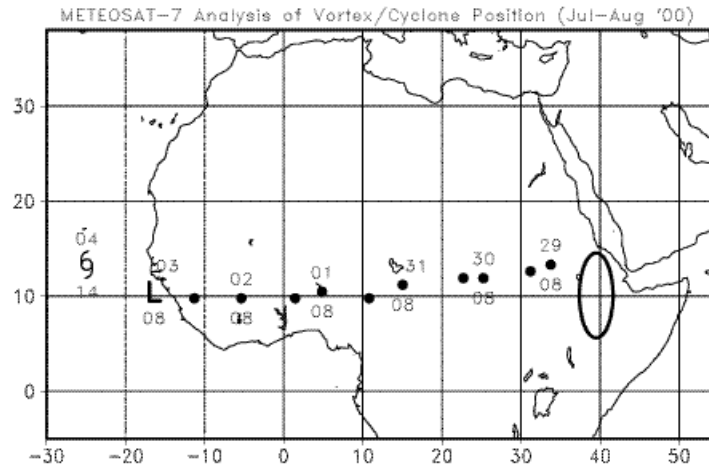
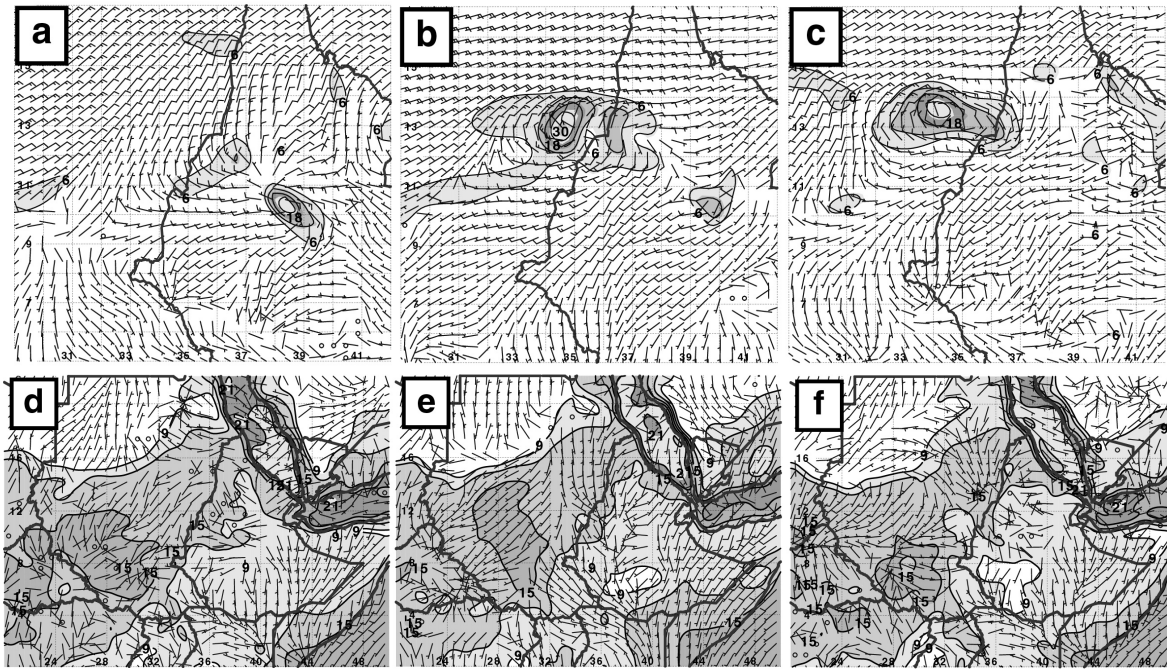


Figure 1. Mesovortex and cyclone center estimated-positions of Alberto (2000) from METEOSAT-7 VIS images for 0830 UTC 29 July 2000 through 1400 UTC 04 August 2000. Every other mesovortex estimated position (dot) and each cyclone estimated position (symbol) is labeled above by the successive day of the month and below by the hour of the VIS image used. Following westward, each system center position is estimated for the alternating times of 0830 UTC and 1430 UTC except for the initial tropical storm position, estimated for 1400 UTC. Oval represents the approximate area of Ethiopian Highlands.

A greatly significant result from the model simulation is the development of mid-tropospheric, mesocyclonic circulation immediately west, and downstream (relative to the African Easterly Jet), of the northern EH. At 18 h (Fig. 2a), two areas of maximum relative vorticity are seen to have developed on either side of the northern EH, with magnitudes of $12 \times 10^{-5} \text{ s}^{-1}$ and $24 \times 10^{-5} \text{ s}^{-1}$. The stronger of the two vorticity maxima to the east of the EH is deemed to be a MV, as the associated cyclonic circulation is closed. Leading up to this time, the base of a monsoon trough over the EH

becomes less distinguishable, suggesting the possible breakdown of associated synoptic-scale vorticity into smaller-scale eddies. These eddies may form the basis for, or at least contribute to the development of, any MVs in the EH region. The smaller area of maximum relative vorticity increases in magnitude to $30 \times 10^{-5} \text{ s}^{-1}$ by 30 h (Fig. 2b) and becomes a strong MV, while the original MV dissipates. By 42 h (Fig. 2c) the surviving, lee-side MV has traveled westward and maintained its structural integrity.

The surface-level moisture necessary to support convective development is found in the humid tropical areas of southern Sudan, with mixing ratio values of 12 to 15 g kg^{-1} . This moisture is advected by southwesterly flow to the western base of the EH by 18 h (Fig. 2d). A secondary source of moisture advection from the Red Sea converges with the moist southwesterly flow over western Eritrea. The advection of moisture from the Red Sea is halted by 30 h, while the moisture advection from southern Sudan continues (Fig. 2e). This moist inflow from southern Sudan has been reduced by 42 h (Fig. 2f). Even up to this time, however, conditional instability remains prevalent downstream of the MV (not shown). Therefore, daily redevelopment of convection would be expected with the “Alberto” disturbance as long as conditional instability and sufficient upward forcing of the air are present. It is also noted that, during MV development, a semblance of cyclonic circulation is evident along a moisture boundary in western Sudan, perhaps an important feature for the eventual translation of the mid-level MV towards the surface after the model time period.



Based on the analyses of the satellite imagery for Isaac and Joyce, we found that there are five stages of genesis/lysis of the MCC/vortex system: (1) Genesis I: convection develops over near the lee side of the EH and is sustained for about 1 day; (2) Lysis I: convective system begins to weaken and eventually dissipates over a period of about 1.5 days; (3) Genesis II: convection redevelops and continues to grow over a period of about 1 day; (4) Lysis II: MCC begins to weaken and convection dies off completely over a period of about 1 day; and (5) Genesis III: convection again redevelops and propagates offshore of the African west coast, where tropical cyclogenesis begins. Our results are roughly consistent with the genesis and lysis regions identified by the climatological study done by Hodges and Thorncroft (1997).

Preliminary analysis of the sensitivity tests shows that the pre-Alberto mesovortex dissipates into a simple wave in all three tests. The supposed pre-Alberto mesovortex is seen to develop in all three test cases, forming in slightly different locations and times, but cannot be adequately sustained for more than 24 hours after development. More results will be compiled for an article to be submitted to Monthly Weather Review in October 2002.

IMPACT/APPLICATIONS

The understanding and capability of predicting the formation and maintenance of the MCCs and associated MVs over the African continent are essential in understanding and predicting the eventual formation of tropical cyclones over the eastern Atlantic Ocean.

TRANSITIONS

None

RELATED PROJECTS

UCAR project on effects of latent heating and boundary layer on track deflection and rainfall distribution associated with the passage of tropical cyclones over a mesoscale mountain

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PUBLICATIONS

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